Ammonia Engines: A roadmap to decarbonising maritime

Jonathan Hall | Research & Advanced Engineering | 2025/06/17

MariNH3
Clean, green ammonia engines for maritime

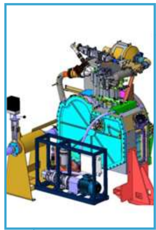
MAHLE Powertrain

Ammonia Propulsion Research
Major Partners

Ammonia Propulsion
Major Topics

Decarbonisation

Combustion



Scale up

Emissions

Mono-Fuel operation

H_2 production

Cold start

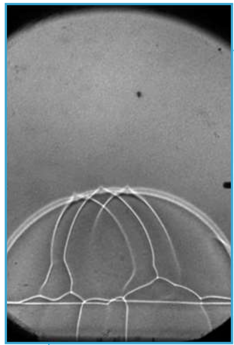
Fuel storage & Preparation

Vessel approval

Technology roadmap to enable the adoption of safe, clean, efficient Ammonia ICE

Ammonia Propulsion
Engine Development Roadmap

Gen 1:
- Retrofit - Dual Fuel
- Diesel fallback
- Carbon Emissions
- Minimum viable combustion



Gen 2:
- Retrofit & OE - Spark ignition
- Full decarbonisation
- High efficiency
- Clean Tailpipe Emissions

Gen 3:
- OE - Fully optimised for Ammonia
- Bespoke combustion architecture
- Advanced Tech. (MAHLE Jet Ignition, Liquid NH_3)

Technology evolution for Ammonia ICE

Ammonia Propulsion
Engine Development Roadmap

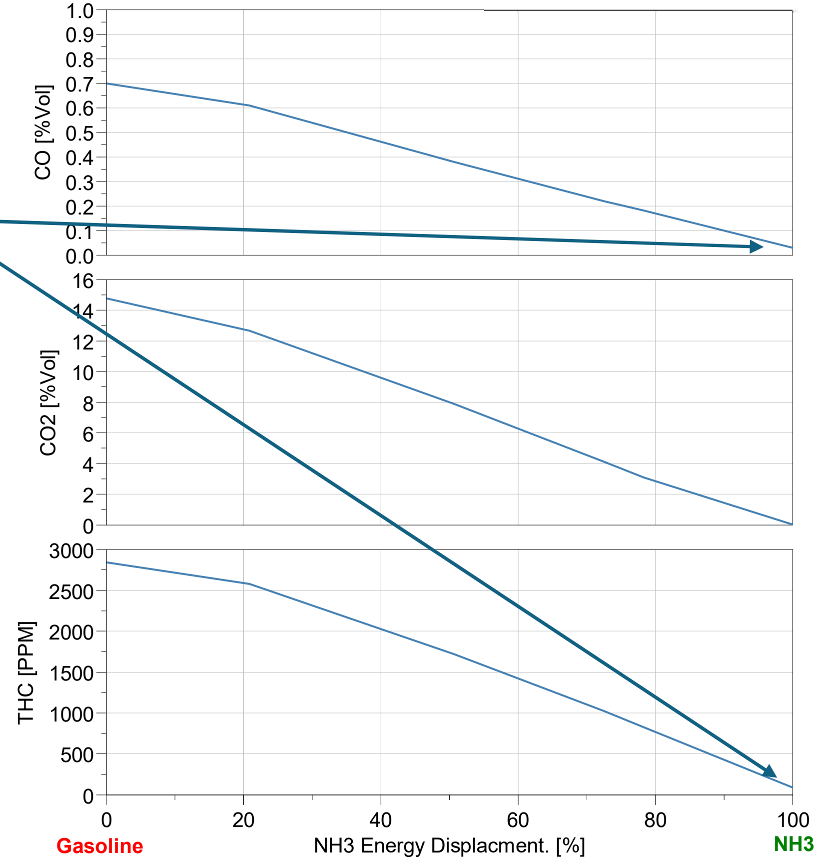
Decarbonisation

- Gen1 Fossil Diesel Dual Fuel
  - Residual carbon emissions

- Gen 2 Pure NH_3 Spark Ignition
  - Trace carbon-based exhaust emissions (lubrication oil)
  - Lower NH_3 slip
  - Less H_2 requirement

Trace CO and HC

Analysers at limit of capability



Status

- 100% ammonia combustion possible
- Full decarbonisation demonstrated
- Zero (trace) CO_2, CO, HC

ICE Emissions Decarbonisation using Ammonia

Ammonia Propulsion
Engine Development Roadmap

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Global Warming Potential (GWP)

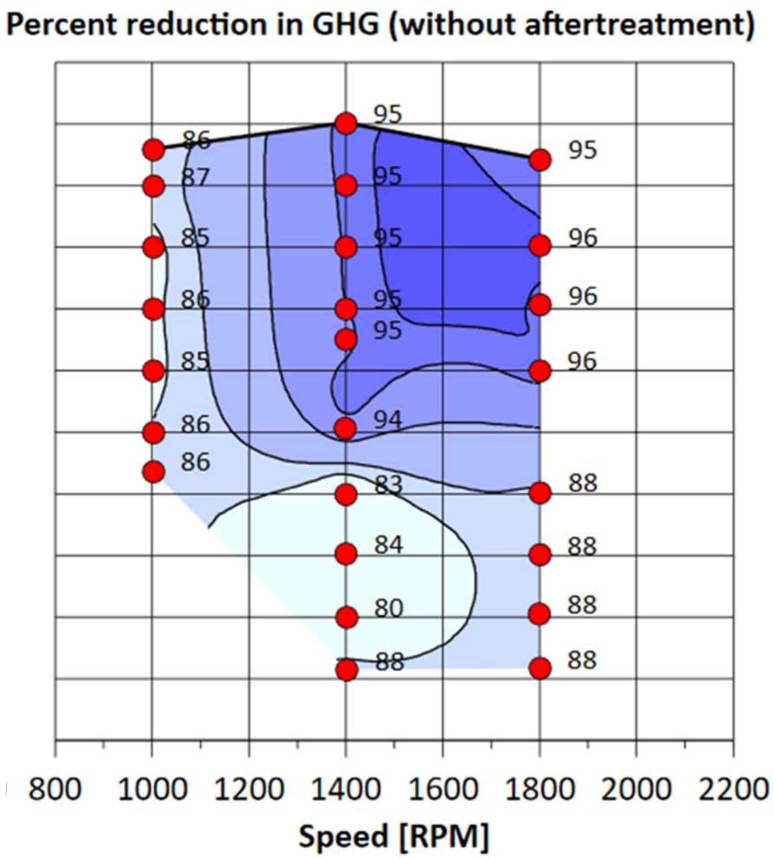
- Must also consider Global Warming Potential (GWP)

- Useful GWP numbers:

	GWP_{20}	GWP_{100}
– Carbon Dioxide (CO_2)*	1	1
– Hydrogen (H_2)**	35	12
– Natural Gas (CH_4)*	81	29
– Nitrous oxide (N_2O)*	273	273
– Ammonia (NH_3)***	0 – 273	

Status

– GWP whole area map produced (right)
– GWP reduction measured at 85-95%



* IPCC Global Warming Potential Values 6th Assessment Report (AR6)
** Sand et al, 2023 doi.org/10.1038/s43247-023-00857-8
*** Ammonium Nitrate decomposition to N_2O as reference for worst case

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Engine Development Roadmap

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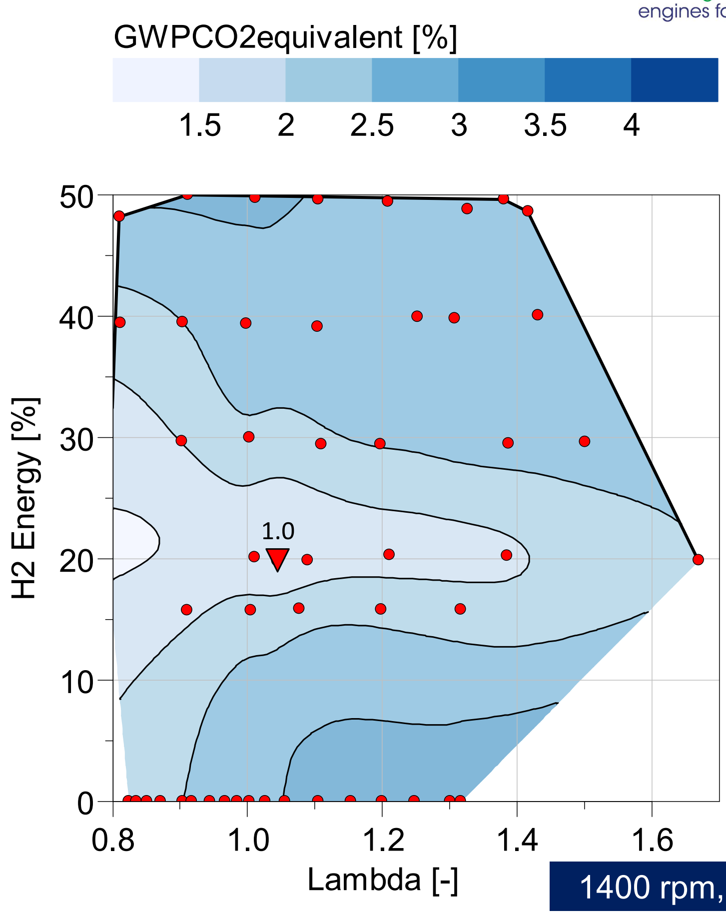

1400 rpm, 14 bar IMEP

Status

– GWP whole area map produced (right)
– GWP reduction measured at 85-95%

Diesel ICE GWP reduced by up to 95% using Ammonia – *demonstrated (engine-out), Next with aftertreatment*

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Engine Development Roadmap

Ammonia Combustion

- Good progress with SI NH_3 combustion

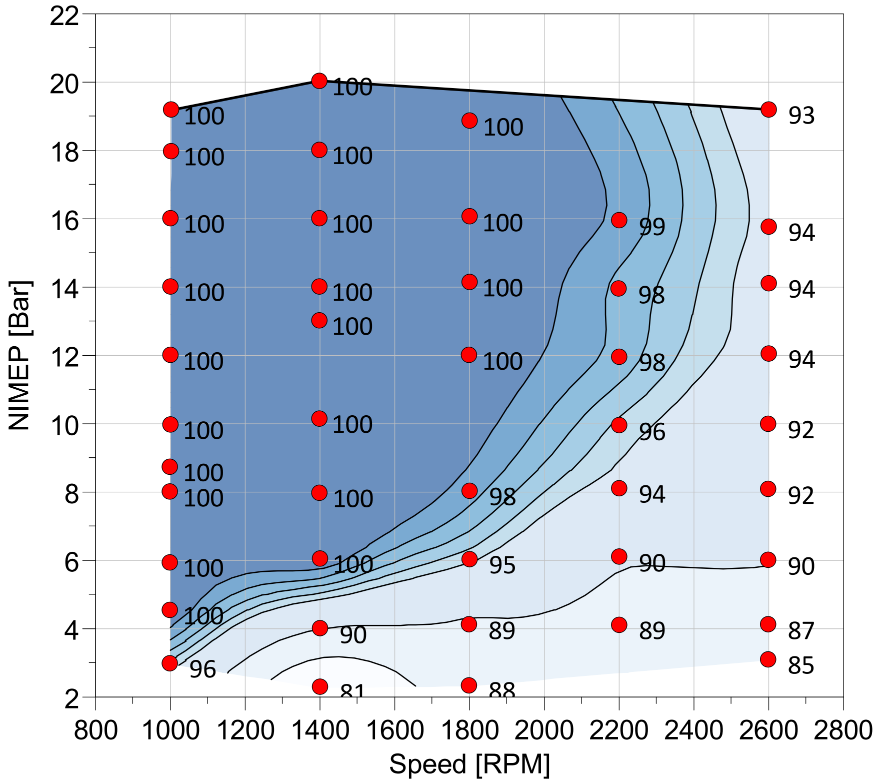
- 100% NH_3 combustion possible
  - Low/Mid-load and higher
  - Lower emissions than Dual Fuel

- Better with H_2 addition
  - Faster & Cleaner
  - Cold start enabler
  - Tuneable emissions (Alpha 1 concept)

Status

- Whole area map operation possible

Ammonia Substitution (% NH_3)



Stable, High-quality, Whole area Ammonia combustion - *further R&D needed for optimisation and higher efficiency*

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Engine Development Roadmap

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Combustion - large bore

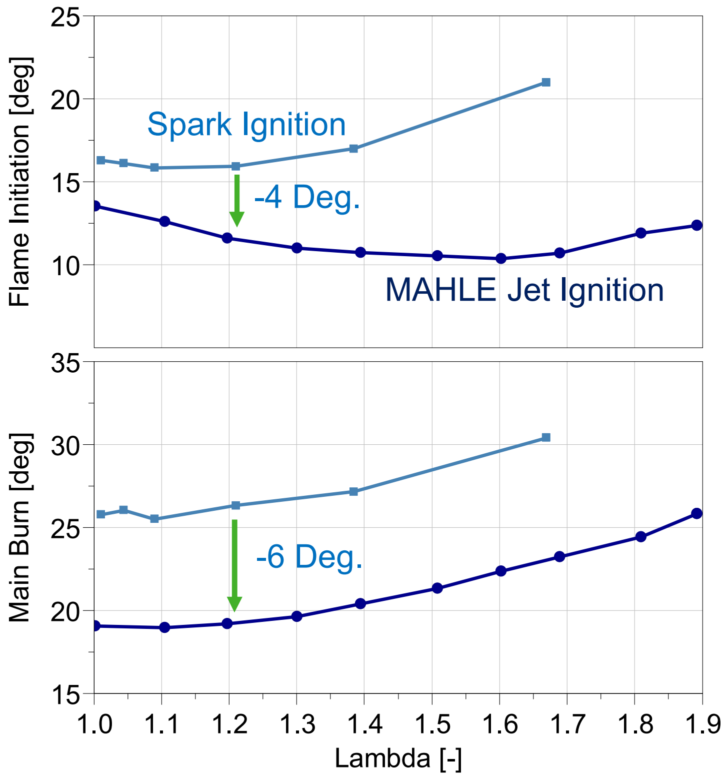
- Slow burn cause issues burning quickly across large bore
  - Limited by flame initiation phase
  - Main burn can be fast
  - Tumble-based combustion and high CR help

- SI may be limiting factor
  - MAHLE Jet Ignition replicates effect of Diesel Injection
  - May enable large-bore 4-stroke
  - Minimises H_2 requirement

Status

- Need to conduct scale up testing on larger bore
  - Volvo D8 & TITANZ

MJI vs SI – Combustion speed differences



Large bore combustion needs to be investigated as the next step – *expecting to need updated ignition technology*

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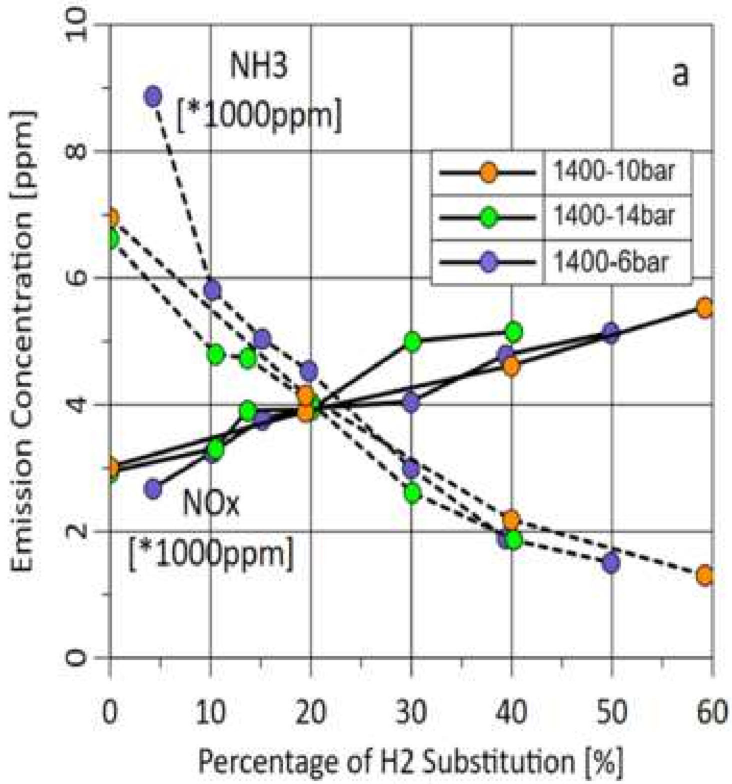
Emissions & aftertreatment

- NOx
  - Temperature & Chemistry
  - Improving modelling methods
- NH_3 slip
  - Poor combustion near surfaces
  - Fuel squeezed into top ring area
- N_2O
  - Formed under lower temperature conditions
  - Can be caused by aftertreatment
  - Highly potent GWP

NOx and NH3 engine-out emissions (*1000 ppm)



Exhaust emissions need to be cleaned up, but initial data suggests this is possible

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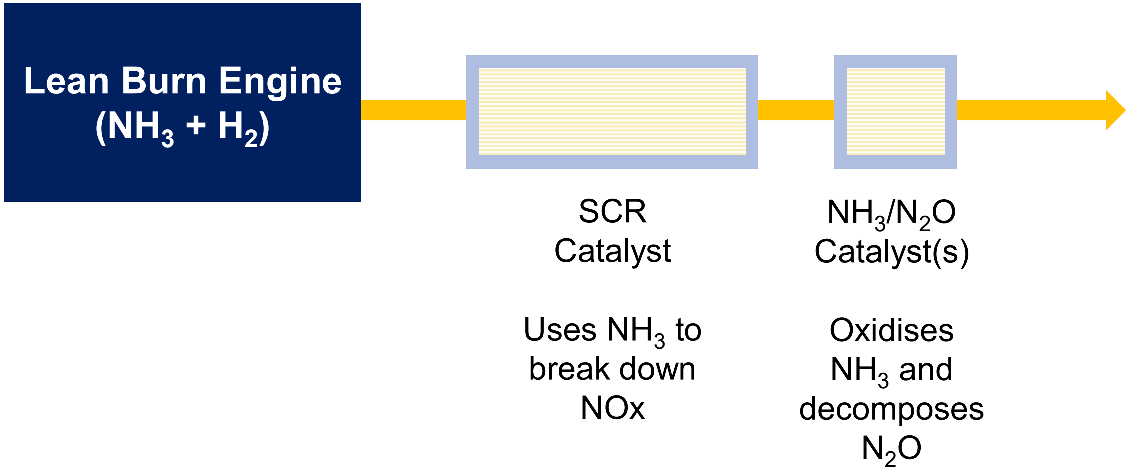
Ammonia Propulsion
Engine Development Roadmap

Clean, green ammonia engines for maritime

Emissions & aftertreatment – Alpha 1

- Alpha = 1
  - NOx ppm = NH_3 ppm
  - Enables Selective Catalytic Reduction (SCR) system to convert *harmful* NOx and NH_3 into *harmless* N_2 and O_2

Targeting:
>95% GWP reduction
<10 ppm NH3
<10 ppm NOx



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Engine Development Roadmap

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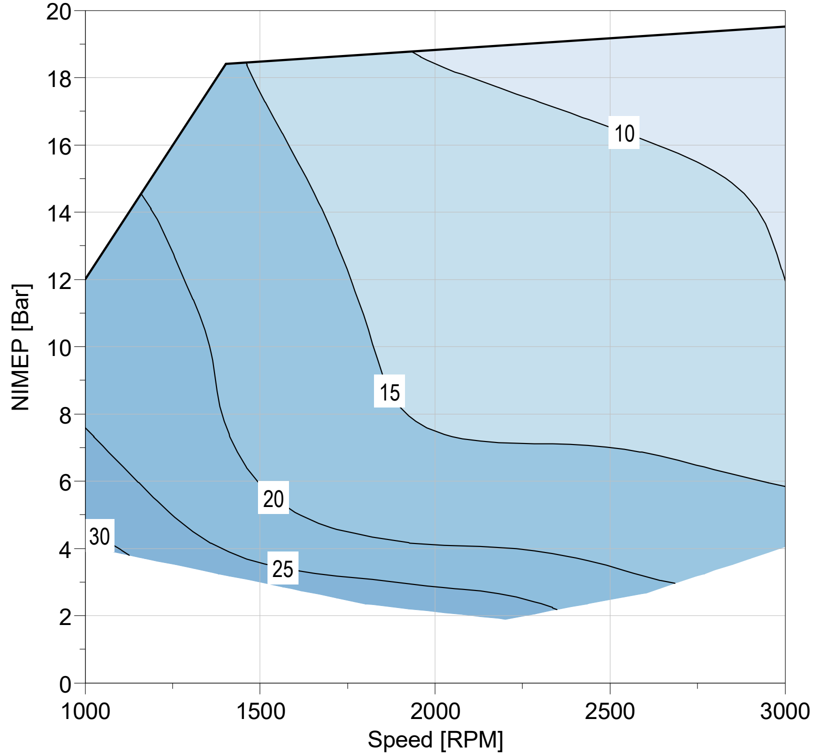
Status

- Whole area Alpha 1 mapped on SCRE
- H_2 substitution requirements known

Next steps:

- Demonstrate Alpha 1 with aftertreatment system on SCRE
- Assess requirement for ammonia oxidation catalyst

Whole area Alpha = 1 H_2 requirement



Alpha 1 concept is key to clean exhaust emissions – *preparation for testing under way with MPT/UoN/JM*

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Engine Development Roadmap

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Single-fuel operation

- Single fuel tank
- Simplified refuelling infrastructure
- Simplified heath and safety
- Smaller fuel storage
- Lower cost

Challenges

- H_2 needed for acceptable ammonia combustion
- Need to generate H_2 live on engine
- Ammonia cracker…

https://www.mitsui.com/jp/en/topics/2023/1245792_13949.html

Single fuel operation expected to bring practicality, safety and cost benefits

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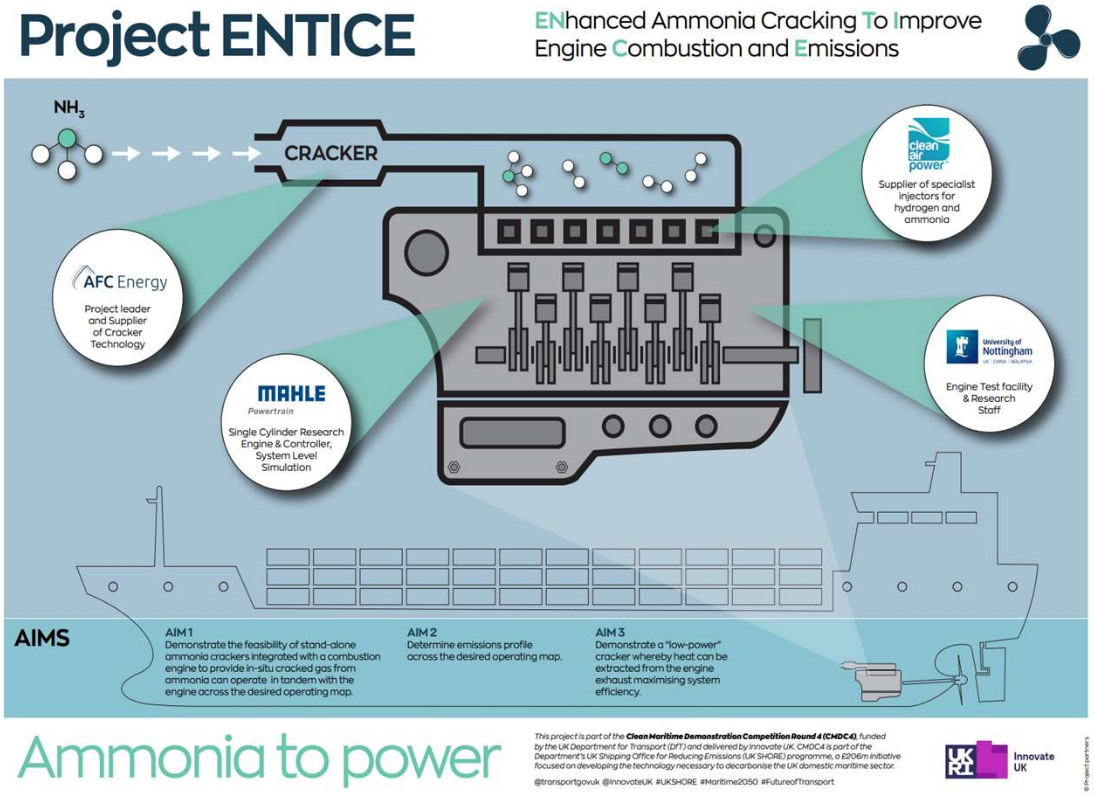
Engine Development Roadmap

On-board H_2 production - Cracker technology

- Catalytic converter
  - Splits NH_3 into H_2 and N_2
  - Requires heat to enable conversion

CMDC4: ENTICE

- AFC Energy cracker integrated to engine
- Live cracking performed across whole area map



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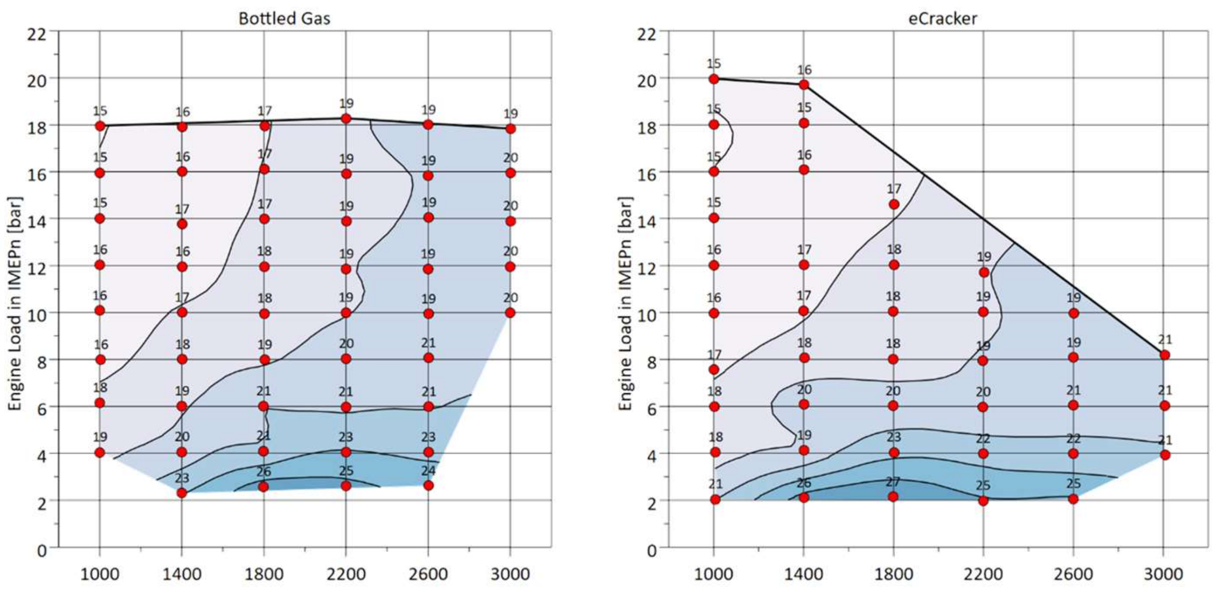
Engine Development Roadmap

Combustion initiation (MFB 0-10%)



No change in behaviour with cracker gas

On-board H_2 production - Cracker technology

- Catalytic converter
  - Splits NH_3 into H_2 and N_2
  - Requires heat to enable conversion

CMDC4: ENTICE

- AFC Energy cracker integrated to engine
- Live cracking performed across whole area map

Nitrogen effect

- Negligible effect on combustion speed or stability
- Additional NOx formation is a strong effect

Single fuel operation needs an on-board ammonia cracker technology to provide H_2 for combustion assistance

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Engine Development Roadmap

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Cold start

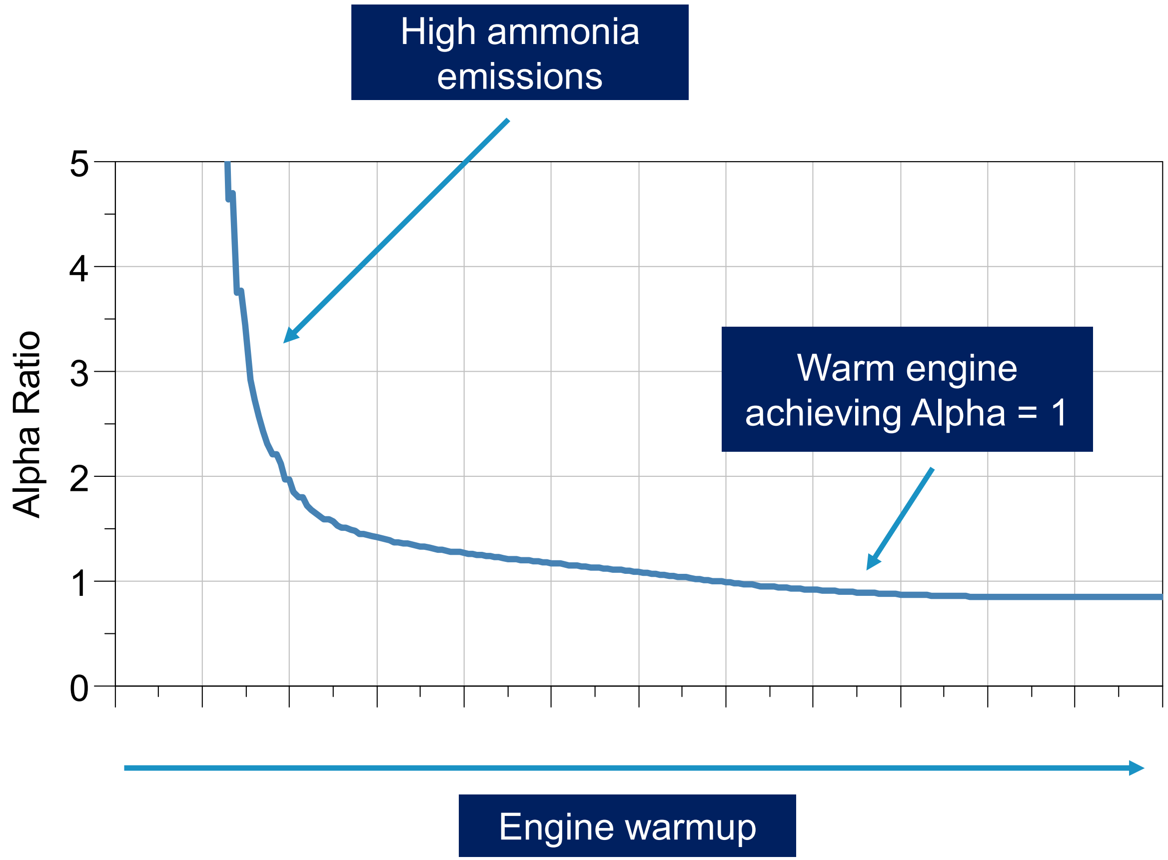
- Cold metal, poor NH_3 combustion
- High H_2 ratio required
- Will need buffered H_2 during cracker warmup

Cracker warmup

- Electric heating
- Cracker size optimisation

H_2 buffering

- Store small amount during normal operation
- Helps NH3 combustion until cracker on-line



Engine and Cracker cold start strategy under development by MPT/UoN/AFC

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Engine Development Roadmap

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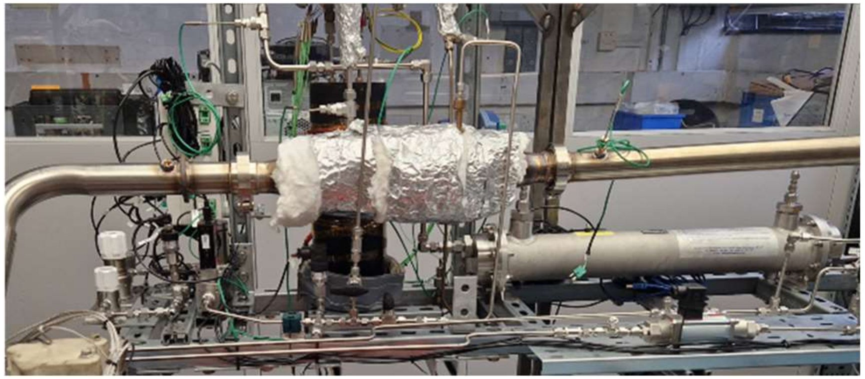
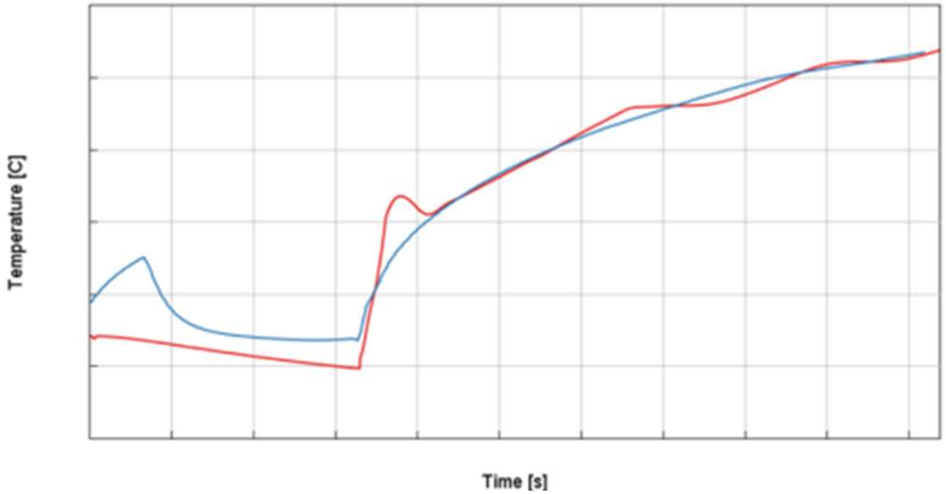
On-board H_2 production - Cracker efficiency

- Waste heat from exhaust
- Minimises electrical consumption

ENTICE

- Engine demonstration of cold start feasibility
  - AFC electrically heated cracker
  - AFC high efficiency regenerative system
    - Harvests energy from waste exhaust heat
- System simulation and optimisation
  - MAHLE Powertrain modelling and optimisation of energy sources, heat exchangers, losses and cracker operation





Benefit of waste heat use on system efficiency tested by MPT/UoN/AFC – *simulation offers insight into improvement*

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Engine Development Roadmap

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clean air power

Fuel handling/conditioning

- Gas:
  - Lots of injectors
  - Evaporation issues at tank
  - Vaporisation equipment needed
- Liquid:
  - Lower temperature combustion
    - Low load challenges
    - High load efficiency benefits
  - NH_3 pumps needed
- UoN pump & vaporisation rig in development, due Q3 2025

Multi gas injector ring assembly

Single liquid NH_3 injector

clean air power™ | ammonia

Liquid NH_3 injection reduced the number of injectors significantly – *testing planned to assess effect on combustion*

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Ammonia Propulsion
Engine Development Roadmap

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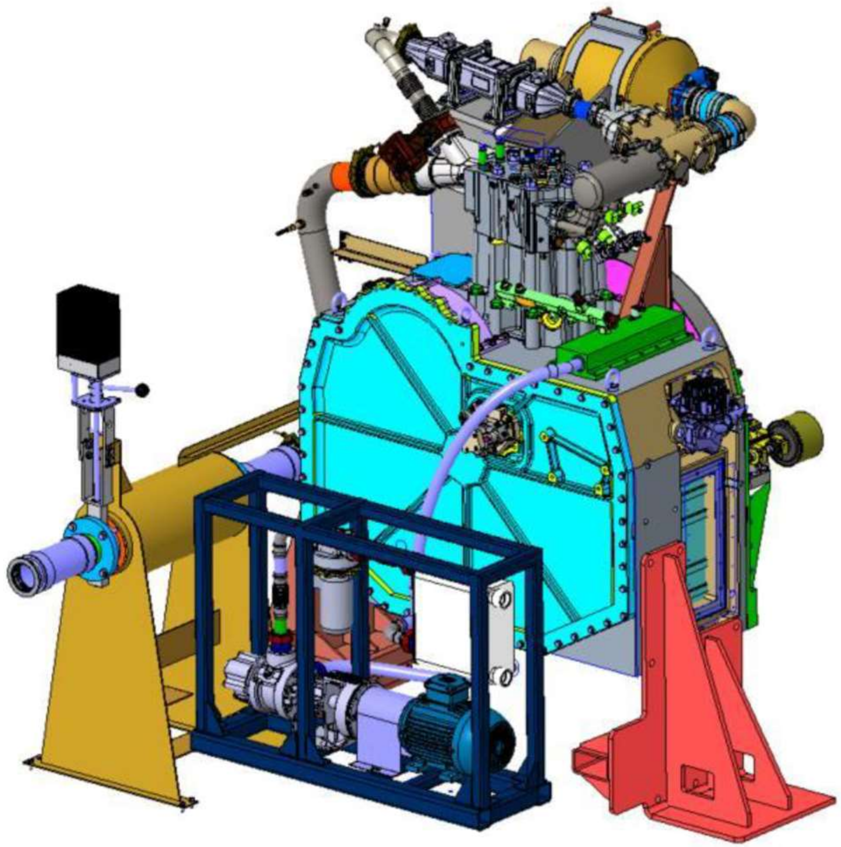
12 month plan

- Aftertreatment demonstration / Development

- Scale up
  - Larger Bore investigations via:
    - Volvo D8 SI conversion (CMDC6 REACT)
    - MTU 4000-based TITANZ
  - Passive & Active MJI experiments
  - Fuel conditioning - UoN rig

- Combustion and system modelling
  - Development of combustion CFD techniques
  - System-level modelling and optimisation



Scale up preparation in progress with REACT and TITANZ projects

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Clean, green ammonia engines for maritime

Ammonia Propulsion
Engine Development Roadmap

12 month plan – System Level Demonstration

- CMDC6 REACT
  - Follow on from CMDC4 ENTICE and MariNH3
  - Gen 2 engine with Clean emissions, Cracker and High output
  - Cold start and emissions control
  - Pre-deployment demonstration in lab setting
  - Preparation for power-gen demonstration project

REACT

Retrofitable Emission-free Ammonia Combustion Technology

CMDC6 REACT will feed into MariNH3 and demonstrate clean, efficient, high power NH_3 at a system level

Ammonia Propulsion
Major Topics – Progress Health Check

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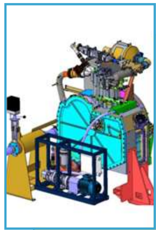
Clean, green ammonia engines for maritime

Decarbonisation

Combustion



Scale up

Emissions

Mono-Fuel operation

H_2 production

Cold start

Fuel storage & Preparation

Vessel approval

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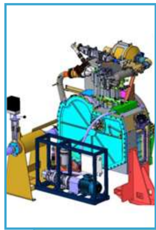
Ammonia Propulsion
Major Topics – Progress Health Check

Decarbonisation
REACT

Combustion
REACT



Scale up
REACT

Emissions
REACT

Mono-Fuel operation
REACT

H_2 production
REACT

Cold start
REACT

Fuel storage & Preparation
REACT

Vessel approval

Roadmap health check shows good progress – *work to do, further R&D needed, but no immovable roadblocks*

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Thank you for your attention & Questions

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